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ECONOMIC ANALYSIS OF FUTURE CIVIL AIR NAVIGATION SYSTEMS.(U)

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Economic Analysis of Future Civil Air Navigation Systems

December 1977

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16. Abstract

This report updates and consolidates the economic analyses of three previous FAA/METREK studies related to future domestic air navigation. Subsequent to the writing of one of these reports, which demonstrated the benefits of VORTAC modernization, the Airway Facilities Service (AAF) made significant revisions to both the F&E and O&M cost estimates for VORTAC modernization. The FAA also updated its estimate of distribution of VOR and DME among the general aviation population. This report documents the impact of these changes. There are no significant changes to both LORAN-C and GPS avionics cost estimates at this time. The study shows that there is no cost advantage in replacing the present VOR/DME system unless more stringent needs, such as area navigation, coverage and accuracy become necessary. Based on the estimated avionics costs the results show that the total cumulative costs (discounted at 10%) to the user plus government, for the various alternatives studied from the year 1985-2010, range from $695 million for VOR/DME, and $865 million for LORAN-C, to $970 million for GPS. It is further shown that if either LORAN or GPS ever became the primary air navigation system, then keeping the VOR for general aviation for a lengthy transition period would be economically attractive.

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CONCLUSIONS

At present the evaluations concerning GPS and LORAN-C accuracy, pilot-workload and other ATC requirements is continuing and for the purpose of this economic analysis it is assumed that both GPS and LORAN-C are technically viable alternatives. The following conclusions are drawn from the economic analyses presented in this report:

1. The FAA should pursue its VORTAC modernization plans from a cost-effectiveness viewpoint, since it appears that VOR/DME would remain in service at least until the year 1995 and the cost of modernization would be amortized through the O&M cost savings by 1988 at no discounting and by 1994 at ten percent discounting.

2. A large portion of general aviation (population over 100,000) who only use VOR, would be cost penalized by about $1100 by LORAN-C and by about $2000 per user by GPS if either of these is adopted as the primary civil air navigation system beyond 1995. However, if either LORAN-C or GPS is adopted as the navigation standard then the concurrent retention of the VOR could be a means to eliminate such a penalty, and this would cost the government an additional $7.0 million per year. Hence, if either LORAN or GPS ever became the primary air navigation system, then keeping the VOR for general aviation for a lengthy transition period appears to be attractive.

3. If the transition to a new system such as GPS or LORAN could possibly be made over an extremely short period, then the present worth of savings at ten percent discounting to the government could be $230 million due to GPS and $130 million due to LORAN-C (Table 5-5). (A majority of general aviation users would still be penalized by GPS or LORAN-C.) However, for the reasons stated in Section 4.1, at least a ten year transition period would be required between the VOR/DME and any new navigation system (either GPS or LORAN-C). The present worth (at ten percent discounting) of GPS savings to the government would then be only $60 million (Figure 5-3); while LORAN-C would not produce any savings as compared to staying with the VOR/DME system.

4. If area navigation becomes a requirement or a dominent factor in the Air Traffic Control system, and if low-cost LORAN-C or GPS avionics is successfully developed, then either LORAN-C or GPS avionics would be cost competitive to a combined VOR/DME/RNAV capability.

RECOMMENDATIONS

From the civil/military commonality standpoint the GPS appears to have a preference over LORAN-C as a possible future civil air navigation system. However, LORAN-C is presently operational for marine use and is presently being flight tested for civil aviation; whereas GPS is still in developmental stages. At the present time, how well GPS would perform in the present ATC environment is unclear and, hence, the following GPS technical issues are recommended for further analysis:

1. Evaluate the feasibility of carrying out non-precision approaches using a low-cost GPS receiver with a limited data rate. If this turns out to be questionable, then evaluate the need for improvements (e.g., air data rate aiding, doppler velocity tracking) and their impact on the receiver costs.

2. Evaluate the time to reacquire signal after losing receiver lock and its impact on approach capability and receiver cost.

3. Evaluate the cost and complexity of a suitable GPS antenna for a general aviation aircraft.

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1. INTRODUCTION

The primary objective of this study, initiated by AEM-200, is to update and consolidate the economic analyses of three previous FAA/METREK future air navigation studies [1,2,3]. The MTR-7140 [1] compared the economics of the present VORTAC* modernization. Subsequent to the writing of that report, the Airway Facilities Service (AAF) made significant revisions to both the F&E and O&M cost estimates for the Second Generation VORTAC. Thus, a need exists to document these changes. The F&E revision is based on a forecasted decrease in the cost of TACAN; whereas the O&M revision is based on the AAF new staffing standard and inflation in technician compensation.

The MTR-7180 [2] had analyzed the feasibility of replacing VOR/DME by LORAN-C. There are no significant changes to the LORAN-C cost estimates. The paper M77-52 [3] is the most recent; it compared the economics of replacing VOR/DME by either LORAN or GPS. Subsequently, the FAA updated its estimate of distribution of VOR and DME among the general aviation population. This report uses the revised distribution. However, the previous conclusions of [2] and [3] are not affected by this change.

Section 2 deals with the near term future of VOR/DME and shows that if the VOR/DME will be in service at least until the year 1995, modernizing the VOR/DME system before 1985 would be economical to the government. Section 3 elaborates further on the GPS receiver cost estimation given in [3]. Section 4 gives the time frame considerations and defines various alternative scenarios. Section 5 presents the economics of the various alternative scenarios in terms of costs to the user, government and the combined costs. The scenarios considered are a continuation of VOR/DME, replacement of VOR/DME or only DME by LORAN-C, and replacement of VOR/DME or only DME by NAVSTAR GPS.

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* VORTAC refers to the colocated VOR and TACAN systems.

2. FUTURE OF VOR/DME

Subsequent to the completion of the previous analysis, which evaluated the cost-effectiveness of a modernized VOR/DME system [1], the Airway Facilities Service (AAF) reevaluated the estimates of both the F&E and O&M costs for the modernized VOR/DME system. The F&E cost of the Second Generation VORTAC was revised from the original METREK estimate of $155 million to $104 million, primarily due to a reduced estimate of the cost of TACAN. The reduction is based on the two DME bids the FAA has received during the last two years.* In reference [1], the cost for TACAN was estimated to be $84 K for a single equipment and $131 K for a dual beacon with a single test, monitor and control (TMC) unit. AAF revised these estimates (June 1976) to $31 K for a single TACAN and $46 K for a dual beacon TACAN based on their recent DME procurements. At about this time (July 1976), METREK again studied the TACAN costs working downward from the military TACAN costs. The METREK estimates were $55 K for a single and $84 K for a dual TACAN. With these TACAN costs, the cost estimate of the VORTAC modernization program would increase from $104 million to about $126 million. The impact of such a cost increase is indicated later. The Congress has appropriated $15 million for FY 78, for the VORTAC modernization. Based on this, the FAA has now proposed a four year program of $104 million for the Second Generation VORTAC beginning FY 78. Note, the modernization program will entail approximately equal numbers of single and dual VOR and TACR facilities according to the Airways Planning Standard. The changes in O&M costs are due to two reasons. First, the old staffing standard (Order 1380.9E) has been replaced by the new staffing standard (Order 1380.40). Secondly, due to inflation, the average cost per FAA technician has increased from $22,080 per employee-year (EY) to $24,694 per EY. Table 2-1 gives the staffing allocation based on the latest staffing standard, for various classes for VORs and TACRs**, along with their population count. Since there are four vintages of single and dual TACANs each, the weighted average workloads are derived for the single and dual TACANs. The average support and administration (S&A) workload for a typical AAF NAS sector is about 34% of the total direct. However, the AAF estimates that the average S&A for the typical VORTAC facility is only about 19%. This is one of the key differences between the old and the new staffing standards.

Table 2-2 gives the Second Generation VORTAC workload estimates which are derived by reducing the PM workload by 75% and the CM

* FAA memo, "Second Generation VORTAC program; FY 78 Budget Item 4a(3) June 22, 1976 by AAF 410.

** TACR refers to the "TACAN only" portion of VORTAC.

TABLE 2-1

WORKLOAD ESTIMATION FOR THE PRESENT VORTAC SYSTEM
PER NEW STAFFING STANDARDS (1380.40)

FACILITY NUMBER*	FACILITY	CLASS	EQUIP.	HOURS PER YEAR										
				ELECTRONIC		ENVIRONMENTAL		TOTAL BASE	OTHER	TOTAL DIRECT	S&A**	TOTAL	EY***	POPULATION
				PM	CM	PM	CM							
1111	VOR	A SINGLE	TUBE	200	51	38	34	323	536	859	163	1022	0.49	158
1111	VOR	B DUAL		254	84	54	45	437	718	1155	219	1374	0.66	714
1221	TACR	1 DUAL	GRN-9 + RTC-1	260	239	0	0	499	579	1078	205	1283	0.62	203
1221	TACR	A SINGLE		263	152	0	0	415	513	928	176	1104	0.53	45
1222	TACR	2 DUAL	GRN-9 + RTC-3	138	189	0	0	327	548	875	166	1041	0.50	7
1222	TACR	B SINGLE		131	36	0	0	167	237	404	77	481	0.23	8
1223	TACR	2 DUAL	RTB-2 + RTC-2	317	204	0	0	521	744	1265	240	1505	0.72	115
1223	TACR	B SINGLE		239	136	0	0	375	488	863	164	1027	0.45	187
1224	TACR	2 DUAL	RTB-2 + RTC-3	182	382	0	0	564	660	1224	233	1457	0.70	25
1224	TACR	B SINGLE		183	165	0	0	348	438	786	149	935	1.45	118
WEIGHTED	TACR	DUAL		261	267	0	0	528	618	1146	218	1364	0.66	350
AVERAGE		SINGLE		247	145	0	0	392	444	836	159	995	0.48	358

* FACILITY NUMBER - AN FAA NUMBER THAT INDICATES VINTAGE AND THE TECHNOLOGY OF THE EQUIPMENT

** S&A - SUPPORT AND ADMINISTRATION = 19% OF TOTAL DIRECT

*** EY - EMPLOYEE YEARS

TABLE 2-2

WORKLOAD ESTIMATION FOR THE SECOND GENERATION VORTAC

FACILITY	CLASS	HOURS PER YEAR										
		ELECTRONIC		ENVIRONMENTAL		TOTAL BASE	OTHER	TOTAL DIRECT	S&A	TOTAL	EY	POPULATION
		PM[1]	CM[2]	PM[3]	CM[4]							
TACR	DUAL	65	134	0	0	199	233	432	82	514	0.25	354
TACR	SINGLE	62	72	0	0	134	152	286	54	340	0.16	354
VOR	DUAL	64	42	14	45	165	271	436	83	519	0.25	436
VOR	SINGLE	50	25	10	20	105	174	279	53	332	0.16	436

1. ELECTRONIC PREVENTIVE MAINTENANCE IS REDUCED BY 75% (SOLID STATF EQUIPMENT + REMOTE MONITORING)
2. ELECTRONIC CORRECTIVE MAINTENANCE IS REDUCED BY 50% (SOLID STATE EQUIPMENT)
3. ENVIRONMENTAL PREVENTIVE MAINTENANCE IS REDUCED BY 75% THROUGH REMOTE MONITORING AND CONTROL
4. ENVIRONMENTAL CORRECTIVE MAINTENANCE REMAINS THE SAME

workload by 50% from the present workload given in the FAA Order 1380.40. This forecasted workload reduction is based on the stability of the solid-state equipment and the use of remote maintenance monitoring. The operational achievability of these reductions within the present AAF maintenance organization has been demonstrated via simulation of the organization [4]. The total workload for the Second Generation VORTAC is then extrapolated from the direct workload by using the total-direct workload ratio for the present system. Table 2-3 derives O&M costs for the present and Second Generation VORTAC using Tables 2-1, 2-2 and other costs derived in MTR-7140. It is pure coincidence that with the new staffing standard and inflation the FY78 O&M cost for the Second Generation VORTAC is estimated to be $19 million per year which is the same as the FY 75 estimate for the Second Generation VORTAC. The supply support, flight check, telephone lines and other objects costs of MTR-7140 are inflated 7% per year to obtain these costs for FY 78. Table 2-4 presents the cash flow analysis of the "do nothing" versus the Second Generation VORTAC alternatives. With no discounting, the Second Generation VORTAC would pay for its capital investment by 1988 while with 5% and 10% discounting* it will pay by 1990 and 1994, respectively. A reasonable discount factor is about 5% because for the last decade the average inflation rate has been about 6 to 7%. Thus, for an average industrial rate of return of 12%, a realistic discounting factor would be about 5%. For this discount factor the payoff date would be 1990. The FY 78 funds of $15 million have already been appropriated by the Congress, if these funds are considered as sunk then the payoff years would be 1987 with no discounting, 1988 with the 5% and 1990 with the 10% discount factor. As outlined earlier, if the VORTAC modernization cost is $126 million instead of $104 million, and if the additional $22 million is added in 1982, then the payoff dates would be 1990 for no discount, 1993 for 5% discount factor and 1999 for the 10% discount factor.

It is apparent from the cash flow analysis presented here that the modernized VORTAC would pay-off its own investment before

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* The Office of Management & Budget in OMB circular A-94, dated March 27, 1972, specified a 10% discount rate. The 10% discount rate is described as an estimate of the average rate of return on private investment, before taxes and after <u>inflation</u>. The 10% figure was calculated by taking the average annual rate of return for U.S. industry from World War II to 1966 and is adjusted for an average of 2% inflation.

TABLE 2-3

PRESENT AND SECOND GENERATION VORTAC O&M COSTS IN FY 78 DOLLARS

	FACILITY	CLASS	NUMBER	STAFFING ALLOCATION IN EY	MANPOWER*	FLT. CHECK + TELEPHONE LINE	SUPPORT	OTHER	TOTAL O&M FOR THIS CLASS
PRESENT SYSTEM	TACR	SINGLE	358	0.48	$11.8K	-	$3.10K	$3.10K	$6448K
	TACR	DUAL	350	0.66	16.3	-	3.10	3.90	8155
	VOR	SINGLE	158	0.49	12.1	$5.23k	1.25	3.43	3477
	VOR	DUAL	714	0.66	16.3	5.23	1.25	4.14	10,220
								Total	$37,300K
SECOND GENERATION	TACR	SINGLE	354	0.16	3.95	-	1.74	2.09	2754k
	TACR	DUAL	354	0.25	6.17	-	1.75	3.50	4043
	VOR	SINGLE	436	0.16	3.95	5.23	0.64	2.64	5433
	VOR	DUAL	436	0.25	6.17	5.23	0.65	2.72	6440
								Total	$18,670k

* COST PER EMPLOYEE-YEAR (EY) = $24,694 WHICH IS FAA'S AVERAGE TECHNICIAN COST FOR THE BUDGETARY ESTIMATE

** ALL COSTS OTHER THAN THE MANPOWER COSTS ARE INFLATED BY 7% PER YEAR FROM THEIR 1975 ESTIMATES

TABLE 2-4

CASH FLOW ANALYSIS OF THE PRESENT VORTAC VERSUS THE SECOND GENERATION VORTAC

(IN FY 78 MILLIONS OF DOLLARS)

YEAR	PRESENT VORTAC, DO NOTHING						SECOND GENERATION VORTAC							
	O&M	PW AT 5% DISCOUNT	PW AT 10% DISCOUNT	CUMULATIVE COSTS			F&E	O&M	TOTAL	PW AT 5% DISCOUNT	PW AT 10% DISCOUNT	CUMULATIVE COSTS		
				NO DISC	5% DISC	10% DISC						NO DISC	5% DISC	10% DISC
1978	37.3	37.3	37.3	37.3	37.3	37.3	15	37.3	52.3	52.3	52.3	52.3	52.3	52.3
79	"	35.5	33.9	74.6	92.8	71.2	30	37.3	67.3	64.1	61.2	119.6	119.6	113.5
80	"	33.8	30.8	111.9	106.6	102.	35	37.3	72.3	65.6	59.7	191.9	182.0	173.2
81	"	32.2	28.0	149.2	138.8	130.	24	34.6	58.6	50.6	44.0	250.5	232.6	217.2
82	"	30.7	25.5	186.6	169.5	155.5		29.2	29.2	24.0	19.9	279.7	256.6	237.1
83	"	29.2	23.2	223.8	198.8	178.7		23.0	23.0	18.0	14.3	302.7	274.6	251.4
84	"	27.8	21.1	261.1	226.5	199.8		18.7	18.7	14.0	10.6	321.4	288.6	262.
85	"	26.2	19.1	298.4	252.7	218.9		18.7	18.7	13.3	9.6	340.1	301.9	271.6
86	"	25.2	17.4	335.7	277.9	236.3		"	"	12.7	8.7	350.8	314.6	280.3
87	"	24.0	15.8	373.	301.9	252.1		"	"	12.9	7.9	377.5	326.6	288.2
88	"	22.9	14.4	410.3	324.8	266.5		"	"	11.5	7.2	396.2	338.1	295.4
89	"	21.8	13.1	447.6	346.6	279.6		"	"	10.9	6 6	414.9	349.0	302.0
90	"	20.8	11.9	484.9	367.4	291.5		"	"	10.4	5.9	433.6	359.4	307.9
91	"	19.8	10.8	522.2	387.2	302.3		"	"	9.9	5.4	452.3	369.3	313.3
92	"	18.8	9.8	559.5	406.0	312.1		"	"	9.4	4.9	471.0	378.7	318.2
93	"	17.9	8.9	596.8	423.9	321.		"	"	9.0	4.5	489.7	387.7	322.7
94	"	17.1	8.1	634.1	441.0	329.1		"	"	8.6	4 1	508.4	396.3	326.8
95	"	16.3	7.4	671.4	457.3	336.5		"	"	8.2	3.7	527.1	404.5	330.5
96	"	15.5	6.7	708.7	472.8	343.2		"	"	7.8	3.3	545.8	412.3	333.8
97	"	14.8	6.1	746	487.6	349.3		"	"	7.4	3 1	564.5	419.7	336.9
98	"	14.1	5.5	783.3	501.7	354.8		"	"	7.0	2.8	583.2	426.7	339.7
1999	"	13.4	5.0	820.6	515.1	359.8		"	"	6.7	2.5	601.9	433.4	342.2

IF FY 78 FUNDS OF $15 MILLION ARE ASSUMED SUNK THEN THE PAYOFF YEARS WOULD BE 1987 FOR NO DISCOUNT, 1988 FOR 5% DISCOUNT AND 1990 FOR 10% DISCOUNT FACTOR.

1995. Thus, it is assumed that the present VOR/DME ground system will have been modernized prior to the implementation of a replacement system. Hence, the cost for VOR/DME modernization is not included in the alternative system's economic analysis.

3. GENERAL AVIATION GPS RECEIVER COST ESTIMATION

This section gives a preliminary estimate of a list price for a general aviation GPS receiver/navigator, assuming that the GPS is selected as the primary air navigation system for the U.S. The objective is to obtain an independent preliminary cost estimate which can be used in the subsequent economic analysis. It should be recognized that this estimate contains some uncertainty since the type of GPS receiver described has not been designed. The methodology is identical to that used for the LORAN-C avionics [2] cost estimation, which was based on that of the previous FAA cost estimation studies for the Microwave Landing System (MLS) and Discrete Address Beacon System (DABS) avionics. This methodology was originally developed in consultation with several manufacturers of general aviation avionics. Two things should be said about the methodology. First, the receiver cost derived here should not be considered as absolute. It is a price relative to VOR and LORAN-C avionics costs. Secondly, the benefit of doubt is given to GPS which may make the GPS cost estimate on the low side. The method involves estimating a typical loaded labor and material cost, which is then multiplied by a factor of four to estimate the list price. The multiplication factor is a function of the potential market volume, competition, and commonality with other avionics. Some of the assumptions inherent in this multiplication factor are as follows:

1. A manufacturer can reasonably expect to sell about 5,000 units a year, assuming that GPS is implemented as a primary civil air navigation system.

2. Because of competition, manufacturers will develop simple, inexpensive designs and keep their prices low.

3. The engineers can refer to an older generation of GPS hardware when developing new designs.

4. There are no radical changes in today's technology and pricing.

3.1 Baseline Features of a Low-Cost GPS Receiver

The following baseline features are assumed necessary for a low-cost GPS receiver/navigator for air navigation. The primary considerations are that the pilot workload should be comparable to a VOR and that the receiver should allow performing a non-precision approach similar to a VOR.

1. Automatic Acquisition

2. C/A Signal only, 1575.42 MHz, 1023 bit Gold Codes

3. Minimum Signal Level = -160dBw

4. Receiver Noise Figure 6 dB

5. No built-in correction for the ionospheric delay

6. Position Tracking using pseudo ranges

7. Velocity Tracking using doppler (Tentative, it needs to be demonstrated if a non-precision approach could be performed satisfactorily using the data rate of a low-cost receiver)

8. Sequential receiver tracking four satellites

9. Must be able to accept a digital altimeter input

10. Nav-algorithm: Should drive a CDI. Exact update every 30 to 60 seconds, approximate in between

11. Input: Time of day, user position, latitude and longitude inputs for way-points, and pseudo range corrections for an approach capability.

12. Output: CDI and a digital display for verification of the input and distance to a way point.

3.2 GPS Receiver Cost Estimation

Figure 3-1 shows a block diagram of a low-cost General Aviation GPS receiver/navigator along with the estimated component costs for various sub-assemblies. The selling price is estimated to be approximately $2,800. These numbers are based on several sources of available information, such as, manufacturer quotes - in conjunction with learning curve effects and mark-up factors - previous METREK avionics cost studies and extrapolation to general aviation from available and projected military Z-set receiver costs.

Previously, two low-cost "Spartan" GPS receiver studies were performed by Magnavox [5] and Rockwell International [6]. Although there is a tremendous amount of valuable technical information in these studies, their cost estimates must be regarded as preliminary.

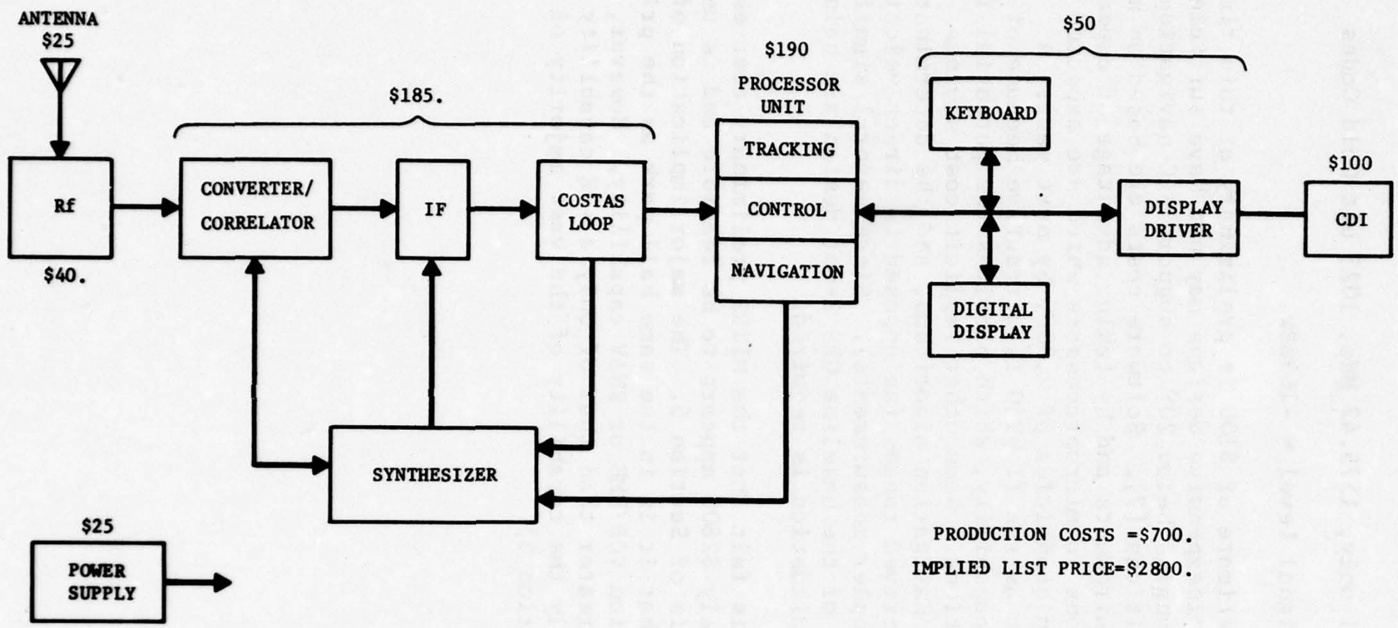


FIGURE 3-1
LOW COST GPS RECEIVER BLOCK DIAGRAM

1. Automatic Acquisition

2. C/A Signal only, 1575.42 MHz, 1023 bit Gold Codes

3. Minimum Signal Level = -160dBw

The antenna cost estimate of $100 is preliminary at this time because the simple inexpensive designs may not have sufficient gain at elevation angles below 20° to support ATC navigation under certain conditions [7]. Software costs are based on minimizing memory requirements and by taking advantage of expected rapid cost reductions in microprocessors which are expected to cost $9.00/unit, in quantities of 2,000, by next year. A microprocessor such as the TI 9940 is attractive because of its hardware multiply capability, which provides the potential for high speed computations. Some other implicit cost savings include simplified navigation algorithms, and the determination of velocity from derived ranges (as opposed to direct velocity derivation from doppler measurements). Since several significant modifications of the baseline GPS Z-set design are being assumed, further validation is required.

In conclusion, it is felt that the MITRE preliminary cost estimate of approximately $2800 appears to be feasible and is used in the cost analysis of Section 5. The major implication of this estimate is that it is in the same ball park as the price of a general aviation VOR/DME or RNAV capability. However, it is significantly greater than that of only a VOR capability which is what is presently the capability of the vast majority of general aviation (Section 5).

4. TIME FRAME CONSIDERATIONS AND SCENARIO DEFINITIONS

4.1 Time Frame Considerations

It is assumed in this study that the earliest date that LORAN could begin to replace VOR/DME is 1985, and the earliest date GPS could begin to replace VOR/DME would be 1990. The rationale for these assumptions are:

1. The test and evaluation for civil IFR en route and approach operations could involve a number of years due to its importance.

2. A viable low-cost airborne equipment operationally suitable for general aviation navigation, for IFR routes and non-precision approach, has not been built and demonstrated for either system.

3. The VOR/DME system is protected by international agreements until 1985, and there is no significant operational requirement that is not satisfied by the present system. Hence, there is no movement afoot in the aviation community to go to a new system.

4. The time required to plan, procure, and implement the mid-continent LORAN coverage necessary for civil aviation would involve at least a few years.

5. GPS is under development, and the final decision for its civil implementation cannot be made until sometime in the 1980s.

A coexistence period would be necessary to protect VOR/DME user investment. Prior navigation system replacements (VOR for Four-Courst-Radio-Range) and future replacements (Microwave Landing System for Instrument Landing System) have provided or will provide for overalp periods in excess of 10 years. Since the current worth of the VOR/DME civil user investment is in the neighborhood of 300 million dollars, and is increasing, it is assumed that at least a 10 year overlap period would be required for amortization of VOR/DME user investment. The foregoing assumptions bring the useful life of the VOR/DME to at least 1995. From the results of Section 2, it is clear that the proposed modernization of the VOR/DME system would be amortized prior to 1995. Hence, the cost for VOR/DME modernization is not included in the economic analysis.

4.2 Replacement Scenarios

Six scenarios have been formulated for economic analysis and are evaluated for the time from the year 1985-2010. These scenarios are:

I. Continue VOR/DME

II. Begin transition to LORAN-C in 1985, overlap VOR/DME until 1995, and phase out all VOR/DME by 2000.

III. Begin transition to LORAN-C in 1985, retain only VOR indefinitely, overlap DME until 1995, and phase out all DME by the year 2000.

IV. Begin transition to GPS in 1990, overlap VOR/DME until 2000, and phase out all VOR/DME by 2005.

V. Begin transition to GPS, retain only VOR indefinitely, overlap DME until 2000 and phase out all DME by the year 2005.

VI. VOR/DME with widespread use of Area Navigation (RNAV)

These scenarios are illustrated in Figure 4-1. The reason for considering the combination Scenarios III and V is that the future LORAN and GPS list prices estimated may be unaffordable for the lowest budget VOR users. On the other hand, a system such as LORAN or GPS that consolidates functions provided today by VOR, DME and RNAV could result in savings to the government without excessive cost to the higher budget navigation users. It will be shown later that for a relatively small additional cost to the government, the scenarios which retain the VOR would provide the minimum total cost (user + government) if LORAN or GPS ever becomes the next national standard for air navigation.

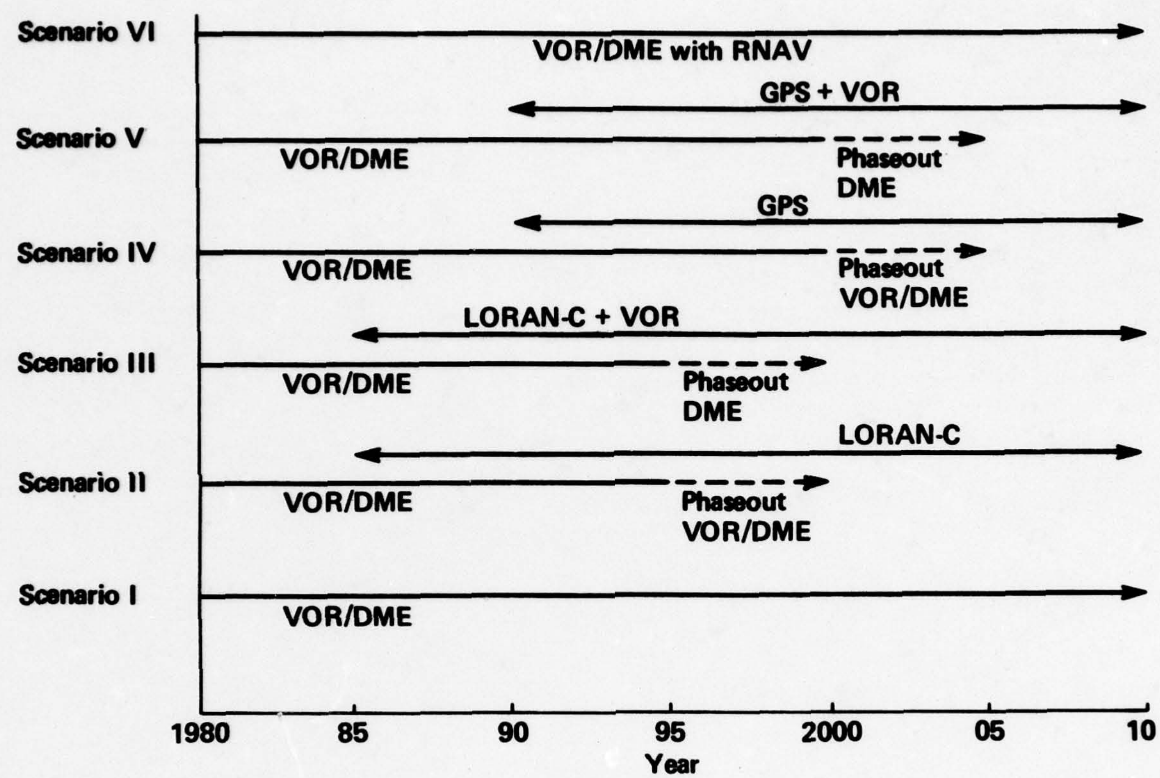


FIGURE 4-1
NAVIGATION SYSTEM ALTERNATIVE SCENARIOS

5. ECONOMIC ANALYSIS

Costs to each user and the government are identified for various scenarios. Cumulative costs are then computed separately for the user and the government for each scenario. It should be pointed out that in reality there is no clear cut distinction between the user and government costs. For the FAA, most of the F&E funds are derived from the trust fund, which is mostly paid through a tax on air-carrier tickets and the O&M costs are paid through the general FAA budget. The analysis considers only general aviation, since they are the vast majority of users. Hence, consideration of airlines has no significant impact on the results.

5.1 Cost to the User

This section evaluates costs to the users for various VOR/DME, LORAN-C and GPS scenarios. Table 5-1 gives the cost estimates, used in the economic analysis, for general aviation navigation equipment in 1985 (in 1978 dollars). Table 5-2 gives the cost of avionics, for the general aviation user classes assumed, for the six scenarios of Figure 4-1.

For the general aviation Class 2, the reason for choosing 1.5 LORAN-C or GPS is as follows. In the VOR world, a dual VOR is frequently needed for VOR or localizer approach procedures. Of course, users may also buy a dual VOR to provide redundancy. In the LORAN or GPS scenario, dual equipment would not be needed from the operational, but rather from the redundancy standpoint. Hence, the decision under complete uncertainty is to assume that one-half of the users of Class 2 buy single while the other half would buy dual LORAN or GPS sets. In the LORAN/VOR and GPS/VOR combination scenarios, the Class 1 and 2 general aviation users are assumed to opt for VOR only due to the significant cost difference between the avionics. Note, that in the VOR/DME with RNAV scenario and the combination scenarios (LORAN/VOR and GPS/VOR) only the Class 3 users are assumed to have area navigation capability.

5.2 Cost to the Government

Cost of VOR/DME Ground System

As derived in Section 2, the annual O&M cost of the Second Generation VORTAC is estimated to be $19 million. Furthermore, in order to keep the VORTAC system running until the year 2010, an investment on the order of $40 million would be required to upgrade the antennas and standby engine generators. For the VOR/DME with RNAV scenario, it is assumed that 60 VORs would have to

TABLE 5-1

1985 COST OF AVIONICS USED IN ECONOMIC ANALYSIS

GENERAL AVIATION	LIST PRICE
VOR	$ 900
DME	1,800
RNAV Computer for VOR/DME	1,000
LORAN Receiver/Navigator	2,050
GPS Receiver/Navigator	2,800

TABLE 5-2

AVERAGE COST OF AVIONICS FOR THE CLASSES OF GENERAL AVIATION USERS CONSIDERED IN THE ANALYSIS

CLASS OF USER			PRICE PER USER FOR EQUIVALENT SYSTEMS IN DOLLARS FOR VARIOUS SCENARIOS					
			1. VOR/DME (No RNAV)	2. LORAN-C	3. LORAN-C +VOR	4. GPS	5. GPS + VOR	6. VOR/DME + RNAV
GENERAL AVIATION	Class 1	VOR LORAN-C GPS	900	2050	900	2800	900	900
	Class 2*	Dual VOR 1.5 LORAN-C 1.5 GPS	1800	3075	1800	4200	1800	1800
	Class 3**	Dual VOR/DME $\underline{+}$RNAV Dual LORAN-C Dual GPS	3600	4100	4100	5600	5600	4600

* 1.5 LORAN-C or GPS means half users buy single and half buy dual.

** Only today's users with DME will buy RNAV computer.

be converted to Doppler VORs at an additional cost of $12 million and the resulting annual O&M costs would be increased to $20 million per year.

Cost of LORAN-C [2]

A $78* million investment is assumed to be required for 13 additional LORAN ground stations. Although there may be a need to perform widespread monitoring of LORAN-C and provide its status to the ATC system, in order to build up confidence in using it for approach, such costs are not included in this economic analysis.

The annual O&M cost of the LORAN ground stations is estimated to be $2.5 million.

Cost of GPS

The cost for the GPS signal-in-space is not considered here since it would be available to civil users as a consequence of the planned military satellite constellation. Although there may be a need to monitor GPS and provide its status to ATC system, such costs are not included in this economic analysis.

Cost of VOR Only [2]

The O&M cost of the VOR only is estimated at $8 million. It is assumed that no significant investment would be required for the modernized VOR.

5.3 Cumulative Costs

Cumulative Users Costs

Table 5-3 gives the estimates of distribution of active U.S. aircraft equipped with VOR/DME during 1975 [8]. Using this information, users of VOR/DME system have been divided into the broad avionics categories in Table 5-4. Cumulative user costs are evaluated assuming a twelve-year life for avionics. Thus, for the LORAN scenarios, beginning in 1985, 8.3% of the users buy new LORAN avionics every year. Similarly, for the GPS scenarios, beginning in 1990, 8.3% of the users buy new GPS avionics every

* DOT is currently in the process of justifying the additional five mid-continent stations solely for land navigation requirements. If this happens, the cost analysis here would have to be modified by subtracing the F&E and O&M costs for these stations.

TABLE 5-3

ESTIMATE OF DISTRIBUTION OF ACTIVE U.S. AIRCRAFT EOUIPPED WITH VOR/DME DURING 1975*

AVIONICS CATEGORY	AIRCRAFT CATEGORY							TOTAL
	SINGLE ENGINE 1-3 PLACE	SINGLE ENGINE 4 + PLACE	MULTI ENGINE <12,500 LBS	MULTI ENGINE >12,500 LBS	TURBOPROP	TURBOJET	ROTOR	
TOTAL AIRCRAFT	63,784	80,802	17,868	1,116	1,905	1,471	4,003	170,949
SINGLE VOR	28,750	23,954	2,037	75	0	0	1,073	55,889
DUAL VOR	4,673	51,676	15,563	1,041	1,905	1,471	308	76,637
DME	1020 (1.6%)	15,918	12,418	1,860	1,524	1,398	--	34,138

* DERIVED USING TABLE 8-1 OF REFERENCE [8] AND THE SINGLE/DUAL DISTRIBUTION OF REFERENCE [9].

TABLE 5-4

BROAD CIVIL AIR NAVIGATION USER AVIONICS CATEGORIES

CLASS	POPULATION IN 1985*	AVIONICS
GENERAL AVIATION CLASS 1	66,800	VOR
GENERAL AVIATION CLASS 2	50,800	DUAL VOR
GENERAL AVIATION CLASS 3	40,800	DUAL VOR + SINGLE DME
AIR CARRIER**	3,210	DUAL VOR + DUAL DME

* OBTAINED FROM 1975 USER POPULATION OF TABLE 5-3 AND A 2% USER GROWTH RATE PER YEAR. ALSO, ALL DME USERS ARE ASSUMED TO HAVE DUAL VORs.

** SOURCE: FAA-AVP-76-77

year. Since VOR/DME and LORAN or GPS would be run parallel for ten years and then VOR/DME is phased down in five years, no user would be forced to buy LORAN or GPS before his VOR/DME equipment is amortized. The annual O&M cost of avionics is assumed to be 5% of the user investment (e.g., if the user investment is $1,000, his annual O&M cost would be $50). The cumulative cost computation assumes a 2% user growth rate. The 1985 worths of cumulative user investment from 1985 until 2010 computed for 0%, 5% and 10% discount factors for each scenario, are contained in Figures 5-1, 2, and 3 respectively. The results indicate the total user investment for VOR/DME (with and without RNAV) and the combination scenarios (LORAN/VOR and GPS/VOR) are within 20% of each other for each discount factor. The user investment for the all LORAN scenario is about 35% more at no discounting and 26% more at 10% discounting as compared to the VOR/DME scenario. The user investment for the all GPS scenario is about 85% more at no discounting and 66% more at 10% discounting as compared to the VOR/DME scenario.

Cumulative Costs to the Government

Using the investment and annual O&M costs of Section 5.2 for each of the scenarios, and 0, 5 and 10% discount factors, cumulative costs to the government are computed. The 25 year operating costs for each of the scenarios, including the cost of overlap with the present VOR/DME system during transition, are contained in Figures 5-1, 2 and 3 for the three discount factors. Due to the cost of the assumed ten year overlap and five year phase out of VOR/DME during transition, the potential for savings to the government through an implementation of LORAN or GPS is doubtful during the time frame 1985-2010. If the transition costs are not considered, as shown in Table 5-5, then the potential savings to the government are clear for the new systems.

Cumulative Costs to the User Plus Government

Figures 5-1, 2 and 3 show total and differential costs to the user plus government for 0, 5 and 10% discount factors respectively. The overall conclusions derived from all the three figures are almost identical. The combination scenarios (LORAN/VOR and GPS/VOR) appear to yield a total cost (user + government) within 15% of that for the VOR/DME scenarios. Whereas, the all LORAN-C and GPS scenarios yield a total cost of more than 40% more than that for VOR/DME.

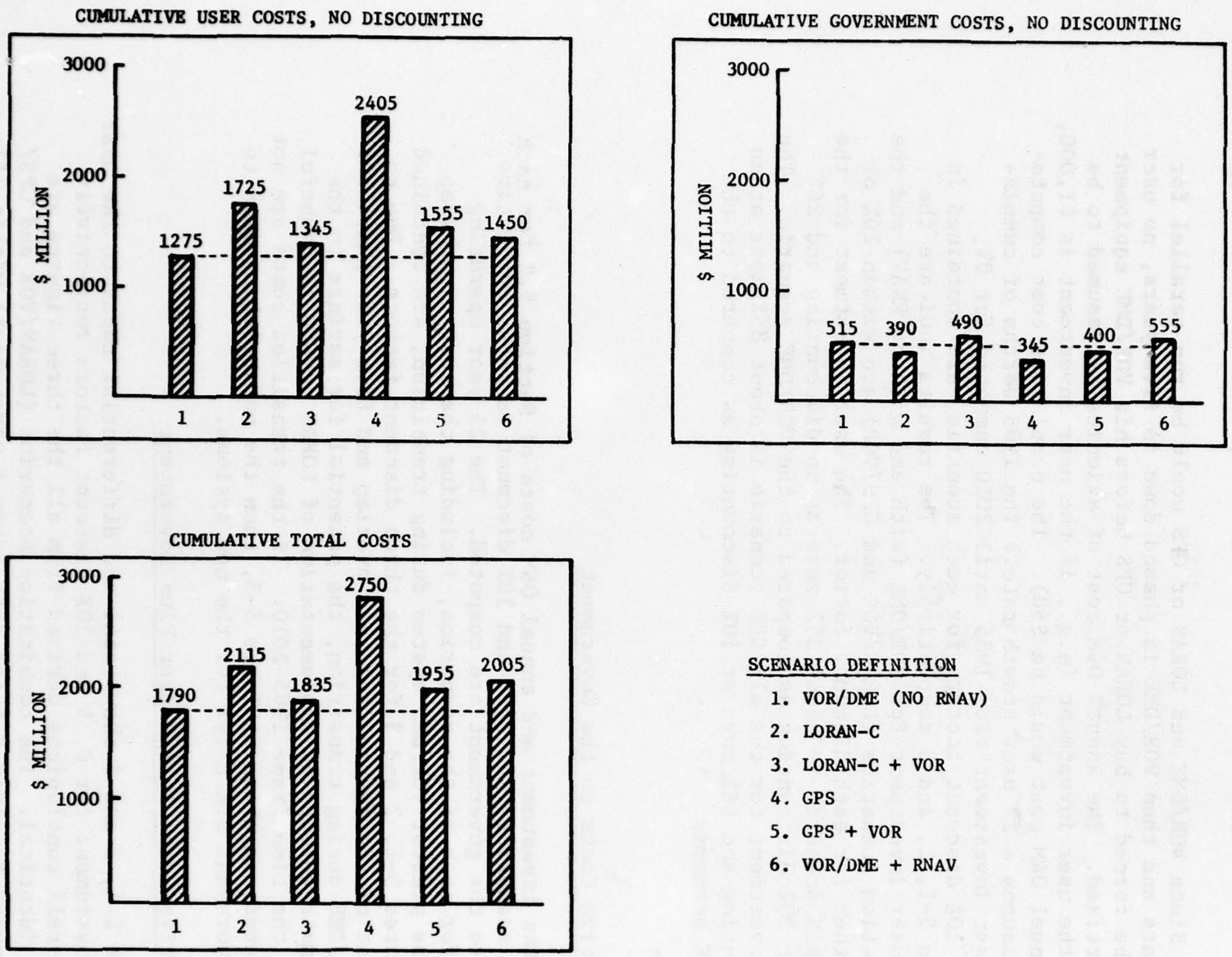
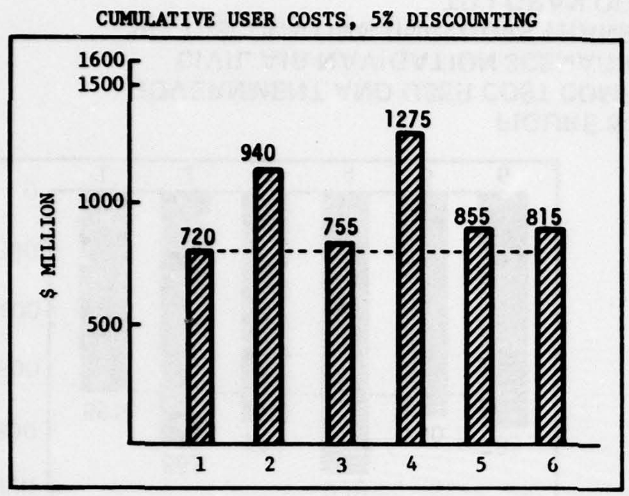
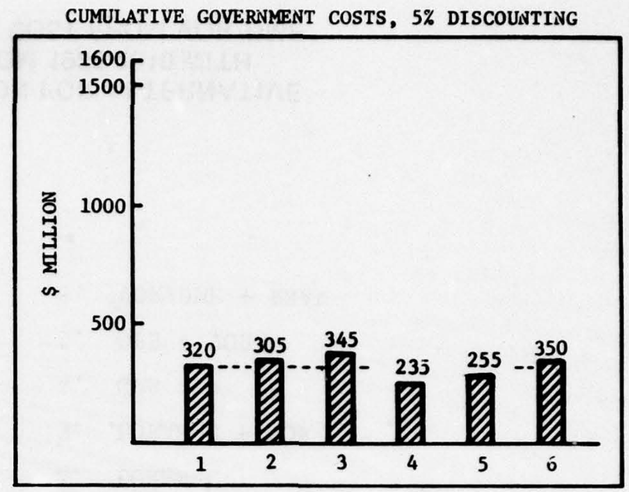
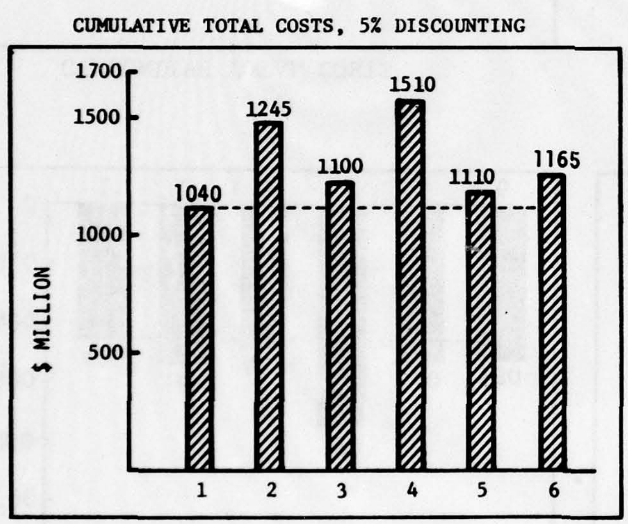


FIGURE 5-1
GOVERNMENT AND USER COST COMPARISON FOR ATTENTIVE NAS NAVIGATION SCENARIOS FROM 1985 TO 2010 WITH NO DISCOUNTING



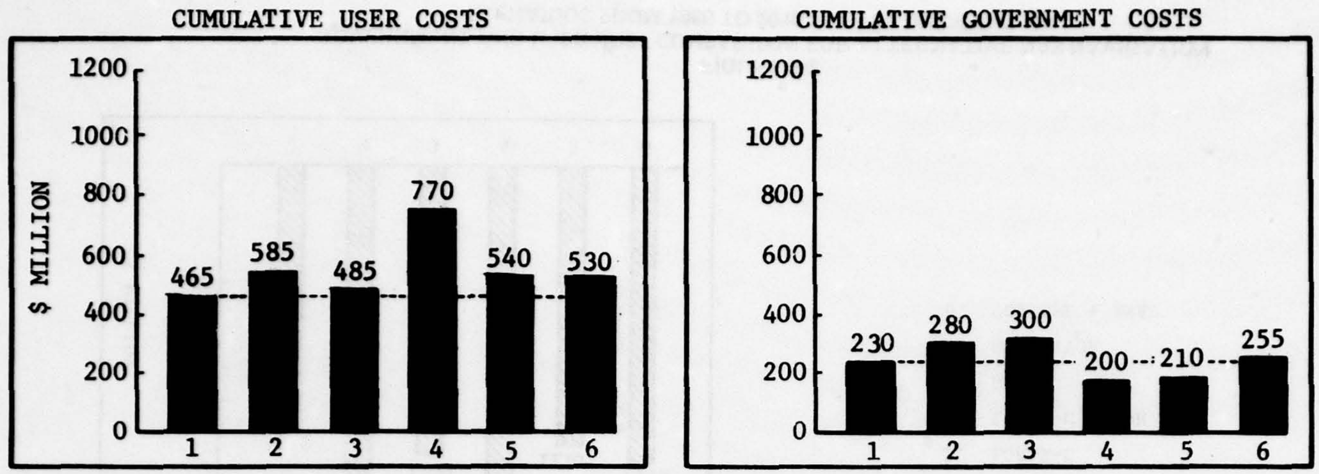


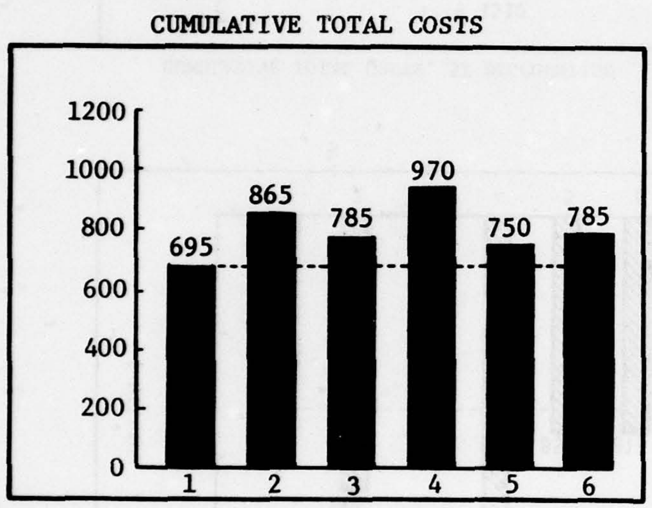


SCENARIO DEFINITION

1. VOR/DME
2. LORAN-C
3. LORAN-C + VOR
4. GPS
5. GPS + VOR
6. VOR/DME + RNAV

FIGURE 5-2
GOVERNMENT AND USER COST COMPARISON FOR ALTERNATIVE NAS NAVIGATION SCENARIOS FROM 1985 TO 2010 WITH 5% DISCOUNTING





SCENARIO DEFINITION

1. VOR/DME (No RNAV)
2. LORAN-C
3. LORAN-C + VOR
4. GPS
5. GPS + VOR
6. VOR/DME + RNAV

FIGURE 5-3
GOVERNMENT AND USER COST COMPARISON FOR ALTERNATIVE CIVIL AIR NAVIGATION SCENARIOS FROM 1985-2010 WITH 10% DISCOUNTING (INCLUDES TRANSITION COST FROM VOR/DME TO LORAN OR GPS)

TABLE 5-5

GOVERNMENT COST COMPARISON FOR ALTERNATIVE CIVIL AIR NAVIGATION*
SCENARIOS FROM 1985-2010

(DOES NOT INCLUDE TRANSITION COST FROM VOR/DME TO LORAN OR GPS)

System	Cumulative Cost to the Government** ($ Million)	Differential Cost to the Government relative to VOR/DME ($ Million)
1. VOR/DME no RNAV	230	-
2. LORAN-C	100	-130
3. LORAN-C + VOR	180	- 50
4. GPS	0	-230
5. GPS + VOR	80	-150
6. VOR/DME + RNAV ***	250	+20

*GOVERNMENT COSTS ARE HIGHER FOR LORAN AND GPS SCENARIOS WHEN THE OVERLAP IS CONSIDERED

**DISCOUNTED ANNUALLY AT 10%

***IT IS ASSUMED THAT IF RNAV IS WIDESPREAD THEN 60 VORs WOULD HAVE TO BE CONVERTED TO DOPPLER VORs.

APPENDIX A

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